

# Origin of silica polymorphs in eucrites: Implications for the crystallization of eucritic magma and metamorphic history of Vestan crust

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## 1. Introduction

Meteorites contain various types of silica polymorphs, and their characteristics provide information about the thermal and shock history of parent bodies. Recently, Ono et al. [1] proposed that the occurrences of silica polymorphs in eucrites are related to the cooling rates determined by mineralogy and compositions of pyroxenes. They concluded that quartz in eucrites transformed from high-temperature polymorphs (i.e., tridymite, cristobalite) by solid-state transition. Tridymite in Y 980433 (cumulate eucrite) was observed after the isothermal heating experiment at 800°C for 96 hr. However, we point out that the following issues can be problematic. (1) Y 980433 originally contains quartz. The observed quartz after the heating experiment is indistinguishable from the original quartz. (2) Y 980433 is categorized to shock degree D [2]. A large amount of tridymite in Y 980433 converts to diaplectic glass (Fig. 1). In their study, we could not confirm the same sample area before and after the heating experiment. Therefore, it is unclear whether the transition from tridymite to quartz really occurred. In our study, we performed isothermal experiments of eucrites, and petrographic observations of the same sample area before and after heating. Moreover, we compare the results with the occurrence of silica polymorphs in several eucrites.

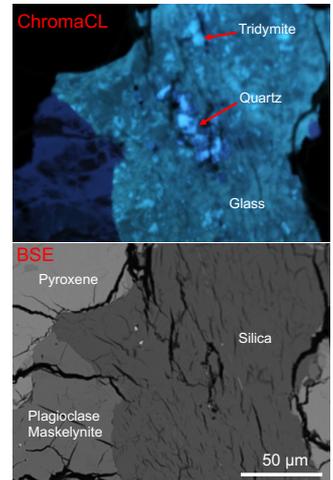


Fig. 1: ChromaCL and BSE images of Y 980433.

## 2. Method and samples

We performed petrographic observations of polished slices using an optical microscope, a FE-SEM (JEOL JSM-7100) equipped with an EDS (Oxford AZtec Energy) and a false color-cathodoluminescence imager (Chroma CL, GATAN), an EPMA (JEOL JXA-8200), and a micro-Raman spectroscope (JASCO NRS-1000) from NIPR. The samples were coated with Os (~5 nm) for SEM observation and EPMA measurements. After petrographic observations, Os coating was removed using a lapping film (3 μm). We separated small chips (~2 mm) from polish slices. Isothermal experiments were performed using the same furnace used by Nakato et al. [3] at ISAS. The chip samples were placed in a stainless steel container, and that was evacuated down to approximately  $1 \times 10^{-7}$  torr using a turbo-molecular pump. We performed two sets of isothermal heating experiments (800°C for 100hr and 1000°C for 100hr). After heating, the samples were cooled to room temperature in a vacuum.

## 3. Results and discussion

### Heating experiments

We used two basaltic eucrites (Agoult, A-87272) as the starting materials for the isothermal heating experiments. These eucrites are classified into different petrologic types [4] and shock degrees [2] (Table 1). Most of the silica minerals in Agoult are MC tridymite. A-87272 contains a large amount of silica glass, minor MC-tridymite and quartz. The silica glass has a lathy shape and higher Al<sub>2</sub>O<sub>3</sub> component (0.21 wt.%), which mineralogical features are comparable to tridymite in other eucrites. Hence, the silica glass in A 87272 is a diaplectic glass of tridymite formed by highly shock metamorphism. Our previous observations indicate that amorphization of tridymite is observed in shock degrees D and E eucrites.

Tridymite in Agoult and A-87272 did not convert to other phases after heating at 800 to 1000°C for 100hr. Silica glass also did not convert to other phases after heating at 800 °C for 100hr. On the other hand, a small amount of silica glass in A-87272 converts to quartz after heating at 1000 °C for 100hr. The facts suggest that the tridymite in eucrites cannot convert into quartz after secondary heating events. Based on our observations, which are inconsistent with Ono et al. [1], we ruled out a formation of quartz from tridymite by the solid-state transition.

### Silica minerals in eucrites

On the basis of our petrographic observations, silica minerals in eucrites are divided into the following four types: (Si-I-III, ungrouped). Si-I is characterized by abundant quartz and minor cristobalite (e.g., Stannern) (Fig. 2a). In the Si-I eucrites, the silica minerals occur mainly in association with large aggregates with opaques (troilite and ilmenite) and phosphate. Si-II is characterized by abundant quartz and tridymite (e.g., Y-75011) (Fig. 2b). In the Si-II eucrites, tridymite occurs as lathy coarse crystals or interstitially between pyroxene and plagioclase. In the tridymite, opaque minerals and phosphate are absent, as in the Si-I quartz. On the other hand, the occurrence of quartz is similar to those of Si-I eucrites. We observed a small abundance of

cristobalite in Si-II eucrites around quartz. Si-III is characterized by abundant tridymite (e.g., Agoult, Moama) (Fig. 2c). In the Si-III eucrites, tridymite occurs as coarse crystals or interstitially between pyroxene and plagioclase without opaques and phosphate, similar to the occurrence of tridymite in Si-II. The Si-ungrouped eucrites are characterized by abundant quartz and tridymite (a coarse-grained portion of Juvinas) but the quartz does not coexist with opaque and phosphate (Fig. 2d). The quartz and tridymite are present in the same silica grain, which shows a sharp grain boundary.

### Origin of silica polymorphs in eucrites

Ono et al. [1] proposed that the combination of silica minerals in eucrites has simply associated with the petrologic types. However, we could not find such relationships between Si-types and petrologic types [4] of eucrites. The fact indicates that the solid-state transition from high temperature polymorphs alone cannot explain the origin of silica minerals. On the basis of our isothermal experiments and petrographic observations, we proposed a new formation process of quartz in eucrites.

Tridymite is a stable phase at P/T condition at the solidus of eucritic magma. Therefore, all silica minerals in eucrite that crystallize in equilibrium conditions become tridymite (i.e., Si-III). On the other hand, it is also known that cristobalite can crystallize from experimentally quenched eucritic melts [1,5]. Ono et al. [1] indicated that the origin of quartz in eucrites is due to a solid-state transition from tridymite and cristobalite. However, we did not observe a phase transition of tridymite to quartz in our experiments. This suggestion is consistent with petrographic observations. The solid-state transition of tridymite to quartz could not explain the occurrence of opaques and phosphate in quartz at such a high frequency. Hence, we propose that quartz is formed from quenched residual melts (probably via silica glass) at disequilibrium conditions. In this case, we can well explain the occurrence of quartz coexisting with cristobalite, opaques, and phosphate (i.e., Si-I). Based on this discussion, Si-II is expected to be found that transitioned from an equilibrium state to a disequilibrium state during the crystallization process. The occurrence of silica minerals in Si-ungrouped eucrites cannot be explained by the crystallization process described above. In this study, we experimentally showed that silica glass transformed to quartz by secondary heating. Hence, quartz in Si-ungrouped formed from silica glass (diaplectic tridymite) by post-shock annealing. Actually, Juvinas is considered to have experienced shock partial melting. This fact is consistent with the amorphization of tridymite and the subsequent annealing.

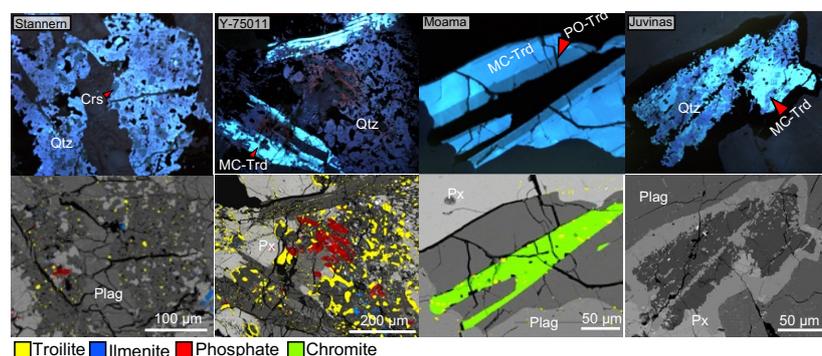


Fig. 2: ChromaCL image and mineral map of eucrites. Stannern is Si-I eucrite which characterized by abundant quartz and minor cristobalite. Y-75011 is Si-II eucrite which characterized by abundant quartz and tridymite. Moama is Si-III eucrite which is characterized by abundant tridymite. Coarse-grained portion of Juvinas is Si-ungrouped eucrite which is characterized by abundant quartz and tridymite (coarse-grained portion of Juvinas) but the quartz is not coexistence with opaque and phosphate. Qtz = quartz, Crs = cristobalite, MC-Trd = monoclinic tridymite, PO-Trd = pseudo-orthorhombic tridymite, Plag = plagioclase, Px = pyroxene.

Table 1. Classification of studied eucrites.

Sample	Petrologic type	Chemical type	Si-type
Y-75011	Basaltic/1	-	Si-II
NWA 049	Basaltic/2	Main group	Si-II
Millbillillie FG clast	Basaltic/4	Main group	Si-I
NWA 7188	Basaltic/4	Stannern group	Si-I
Y 983366	Basaltic/4	-	Si-I
Stannern	Basaltic/4	Stannern group	Si-I
Y-790266 CG clast	Basaltic/4	Stannern group	Si-I
Juvinas FG clast	Basaltic/4	Main group	Si-II
Juvinas CG clast	Basaltic/5	Main group	Si-ungrouped
Y-792510	Basaltic/5	Main group	Si-II
Millbillillie CG clast	Basaltic/5	Main group	Si-II
NWA 5356	Basaltic/5	-	Si-II
A-88174 FG clast	Basaltic/5	Stannern group	Si-III
EET 90020	Basaltic/5	Residual eucrite	Si-III
Agoult	Basaltic/5	Residual eucrite	Si-III
A-87272	Basaltic/7	Residual eucrite	-
Y-791195	Cumulate	-	Si-III
Moore County	Cumulate	-	Si-III
Moama	Cumulate	-	Si-III

CG = Coarse grained; FG = Fine grained

Most of silica minerals in A-87272 are silica glass

### References

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